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MONITORING FRESH WATER RESOURCES

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KANSAS ENVIRONMENTAL AND RESOURCE STUDY:
A GREAT PLAINS MODEL

Monitoring Fresh Water Resources

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PREFACE

This is a report on the third six months of progress achieved in the study of the major reservoirs in Kansas to determine the feasibility of monitoring fresh water resources by satellite. Two reservoirs, Tuttle Creek and Perry, have been the object of intensive study to determine the properties of reservoirs which control the spectral intensity of reflected sunlight as detected by the ERTS-1 sensors. Water samples have been collected from these two lakes concurrent with satellite overpass and have been analyzed to determine the amount of suspended solids, chlorophyll content, and concentrations of phosphate, nitrate, and potassium ions. In addition, water temperature and turbidity at each sample site are measured. ERTS images in four spectral bands (green, red, red-infrared, and infrared) are regularly received for each satellite overpass of Kansas reservoirs. CCT's have been obtained retrospectively for most of the usable passes over the two lakes. These have been processed and the output analyzed to determine the bands and combination of bands which best reflect water quality parameters measured at time of overflight. Experiments with the CCT's have been performed to guide the development of a film analysis technique which makes use of the IDECS (Image Discrimination, Enhancement, and Combination System) which together with the software system KANDIDATS (Kansas Digital Image Data System) provides an analog-digital approach.

I. INTRODUCTION

The major reservoirs in Kansas, as well as in other Great Plains states, are playing increasingly important roles in flood control, recreation, agriculture, and urban water supply. A method for acquiring timely low cost water quality data is needed to achieve optimum management of these fresh water resources. The goal of this ERTS 1 study is to test the feasibility of using satellite imagery to monitor suspended load and chemical concentrations in Kansas reservoirs which should be representative of most Great Plains reservoirs.

Weather and clouds permitting, 10 water samples from two reservoirs, Perry and Tuttle Creek, are collected during each ERTS 1 overpass. The water samples are being analyzed for concentrations of inorganic suspended and dissolved solids, organic suspended and dissolved solids, chlorophyll, potassium, phosphate, and nitrate ions. In addition, secchi disc and temperature measurements are taken at each sampling station.

II. WORK PERFORMED DURING THIS REPORTING PERIOD

During this period, work has centered on the processing and analysis of 7-track computer compatible tapes ordered for cloudless ERTS-A passes for which ground truth was acquired. Digital levels for each water sample station have been extracted from the CCT by locating the sample station coordinates on a CCT generated gray level map and averaging 9 pixels centered around the coordinate. This cell corresponds to a 240 x 240 meter area on the water surface.

Thus far, CCT's for 11 reservoir passes have been processed. These 11 passes represent, of course, different sun angles and sky conditions. The reflectance levels from the concrete dam at Tuttle Creek Reservoir, a target with constant spectral reflectance, demonstrate a strong sun angle dependence in all MSS bands (Figure 1). As has been suggested by Vincent (1972), the sun angle dependence is suppressed by plotting band ratios instead of absolute levels (Figure 2). The three other possible ratios, not plotted in figure 2, also show a flat response to change in sun angle. Ratioing essentially removes the effect of unequal illuminating intensities caused by the continuously changing sun angle from one ERTS pass to the next. Since the ratio curves for the dam are flat, the angle of incidence and atmospheric scattering of reflected light are not important factors, at least for a concrete target.

Water reflectance levels do not exhibit as strong a dependence on sun angle, but there is a significant measureable effect (see Figure 3 for band 5 example). As for concrete, the absolute, reflectance levels for water decrease with lower sun angle. In addition, the correlation (or slope) between reflectance level and suspended solids, in the range 0 - 90 ppm, appears to depend on sun angle. On the other hand, the magnitudes of MSS5/MSS4 ratios are indistinguishable for the three different sun angle passes (Figure 4). The slopes (ratio vs. suspended solids) for the two low sun angle passes remain fairly flat. A dark object subtraction on each band before ratioing, as suggested by Vincent (1972), does not significantly change the slopes of the three passes. Dark object subtraction, which is the absolute level detected by ERTS minus level of darkest object in scene, should suppress atmospheric scattering effects present in the ratios. These results indicate that the slope dependence on sun angle is probably not due to atmospheric scattering. It is perhaps due to water column reflectance dependence on sun angle of incidence.

There were no obvious anomalous conditions during the low sun angle passes such as high wind or chemical concentration. Lower temperatures should not significantly effect water volume reflectance (Scherz, 1971). Reflectance levels from the 8 passes with sun angle $\geq 45^\circ$ exhibit much weaker dependence on sun angle, but ratioing nevertheless improves correlation with suspended load, particularly for bands 4 and 5. The 3 passes with sun angle $\leq 40^\circ$ exhibit lower correlation with suspended load, but the suspended load range 20 to 60 ppm is small compared to the range 0 to 900 ppm for all the data. More points at higher suspended load and low sun angle are needed to statistically confirm a band ratio-suspended solids correlation dependence on sun angle. For the remaining discussion it is assumed that, after ratioing, sun angle dependence is relatively unimportant.

Band 4 shows no correlation beyond ~50 ppm and is useful only for relatively clear water (Figure 5). This green band penetrates the water column more than the other bands, but as a consequence encounters a large amount of scattering material which produces saturation or maximum scattering at levels $\lesssim 50$ ppm. Band 5 is correlated with somewhat higher turbidities (≈ 80 ppm) but its response to suspended load is quite similar to band 4 (Figure 6). Band 5 ratioed with band 4 (Figure 7) improves suspended load correlation and is roughly linear in the range of 0 to 80 ppm with RMS residual of 12 ppm (Figure 8). All regression analysis in this report was done with horizontal axis as the dependent variable and vertical axis as the independent variable.

Band 6 and the ratio band 6/band 4 display good correlation with suspended load over the entire range of 0 to 900 ppm (Figure 9 and 10). A smoothly varying polynomial fit yields an RMS residual of 31 ppm. A similar fit (not shown) to the non-ratioed curve in figure 11 yields an RMS residual of 48 ppm, so that a significantly better fit was achieved by ratioing. As is the MSS5/MSS4 ratio, the MSS6/MSS4 is linearly related to suspended solids in the region ≤ 100 ppm (Figure 11). The response of band 7 (not shown) and band 7/band 4 (Figure 12) to suspended load is somewhat weaker than the other bands but is definitely correlated with accuracy level ~ 50 ppm.

Figure 13 is an example of a suspended solids contour map of Tuttle Creek Reservoir (August 14, 1972) which was produced using a correlation curve between band 5 and suspended solids. The curve (not shown) was derived from four high sun angle passes which yielded an RMS residual of 5 ppm.

Band ratio correlations with secchi depth (or maximum light penetration depth) are shown in Figures 19, 15, and 16. The MSS5/MSS4 ratio is able to predict secchi depth (or water clarity) to within ± 20 cm to at least a 1 meter depth, which is the limit of this investigation. The ratios MSS6/MSS4 and MSS7/MSS4 yield reliable results for the more turbid water conditions corresponding to secchi depth in the range 0 to 40 cm and 0 to 20 cm respectively.

A study of ratio curves for MSS6/MSS5, MSS7/MSS5, and MSS7/MSS6 (not shown) indicates that these ratios are not very useful for correlations with suspended load or secchi depth.

Also during this reporting period, progress has been made toward developing a visual technique of studying reservoirs on 9.5" ERTS positives. This technique involves the use of the IDECS under program control. Reservoir images under study are level sliced on the basis of the 15-step-density wedge accompanying each image which represents divisions of equal incoming power. Each of these divisions is further broken up into smaller units, and the end product will be a reservoir map contoured on the basis of reflective strength. Since it has been demonstrated that inorganic suspended load dominates the reflection levels of Kansas reservoirs, it will be a simple matter to also generate a contour map of suspended solids concentration.

Knowledge concerning water reflective properties and the influence of sun and sky conditions gained through the analysis of CCT's is guiding the development of this visual technique. Data extracted from these tapes is also being used as a standard to which visual results will be compared in an effort to achieve reliability.

III. NEW TECHNOLOGY

None.

IV. PROGRAM FOR NEXT REPORTING PERIOD

As this report is written, development of a quantitative visual image analysis technique is near at hand and should be completed during the remaining months of the project. This technique will receive full attention during the next period since lake sampling is completed and virtually all required data is available.

V. CONCLUSIONS

Inorganic suspended load is the dominant influence on reservoir reflection levels. MSS band ratios derived from CCT's can be used for reliable prediction of suspended load up to 900 ppm during at least the high sun angle warmer months and perhaps the entire year (see discussion on sun angle). The ratio $MSS5/MSS4$ is useful in the range 0 to 80 ppm with accuracy on the order of 10 ppm. The ratios $MSS6/MSS4$ are useful from 0 up to at least 900 ppm, which is the limit of this investigation, with accuracies of 30 ppm and 50 ppm respectively.

VI. RECOMMENDATIONS

None.

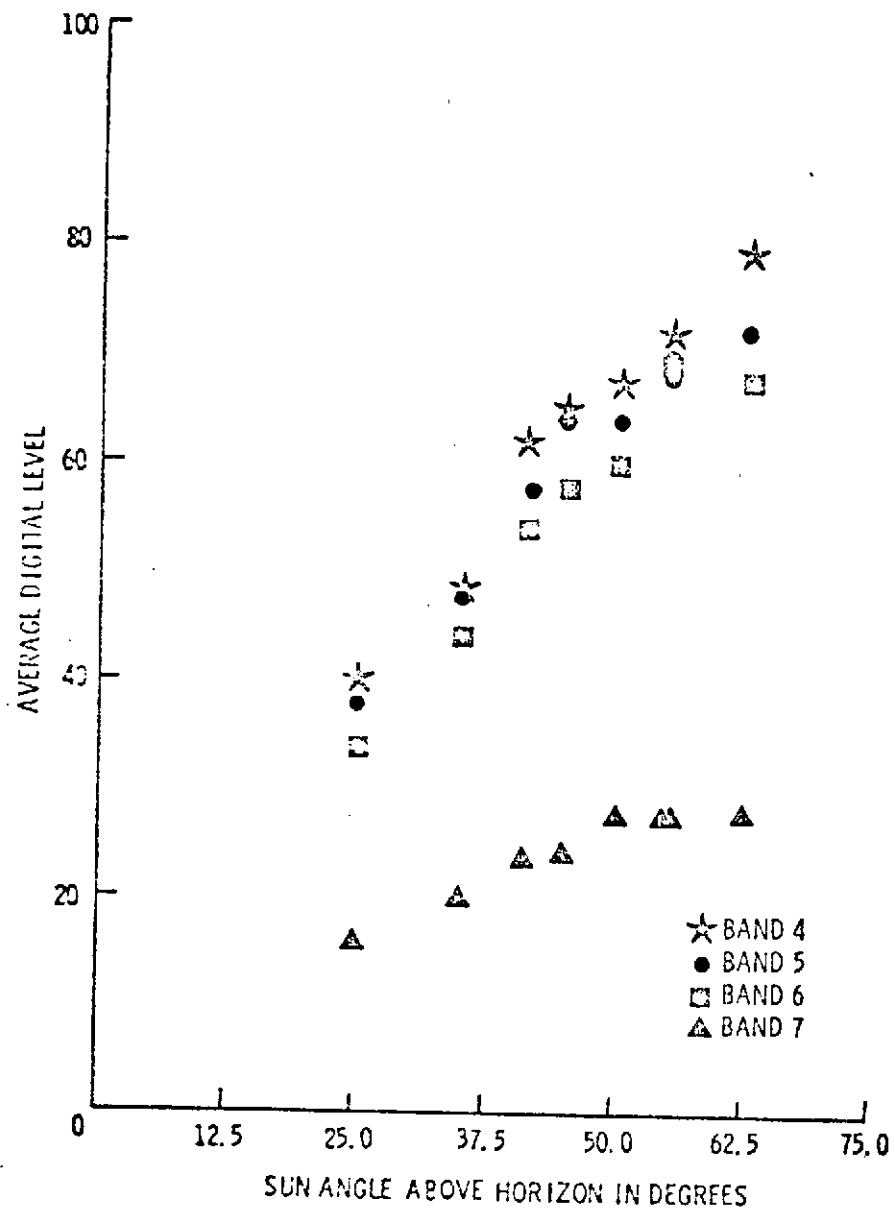


FIGURE 1. MSS DIGITAL LEVELS FROM CCT VS. SUN ANGLE FOR TUTTLE CREEK CONCRETE DAM.

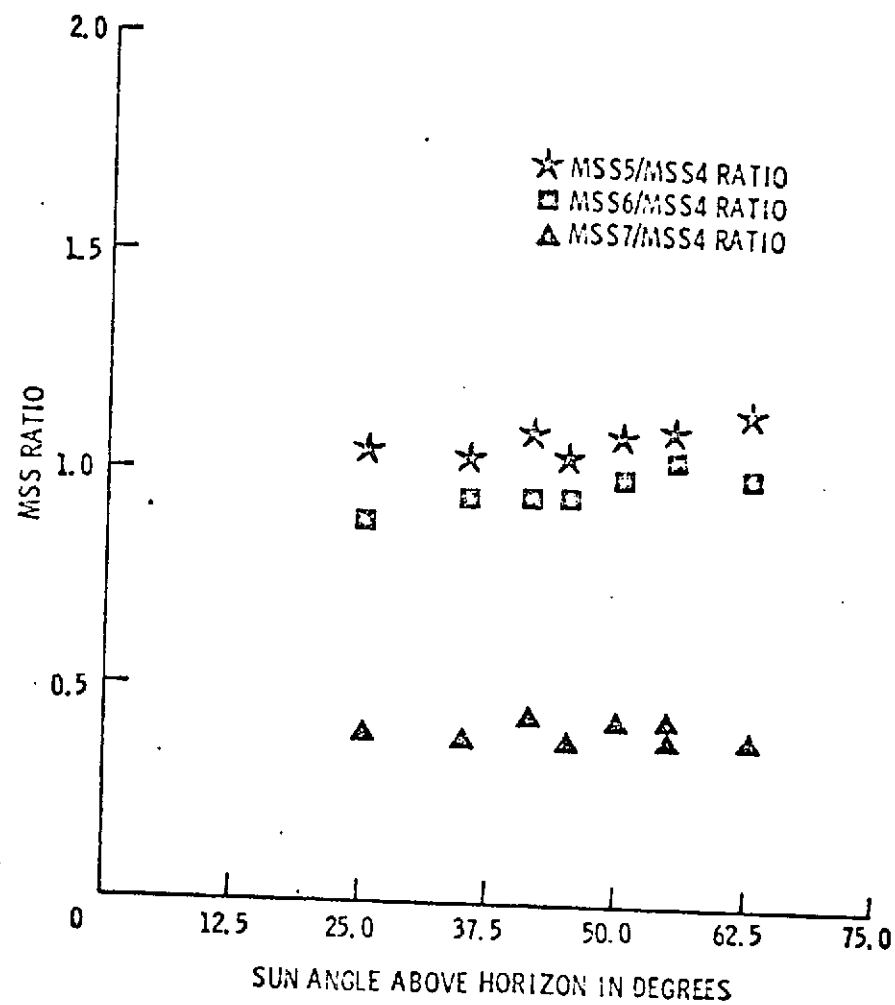


FIGURE 2. MSS BAND RATIOS FROM CCT VS. SUN ANGLE FOR TUTTLE CREEK CONCRETE DAM.

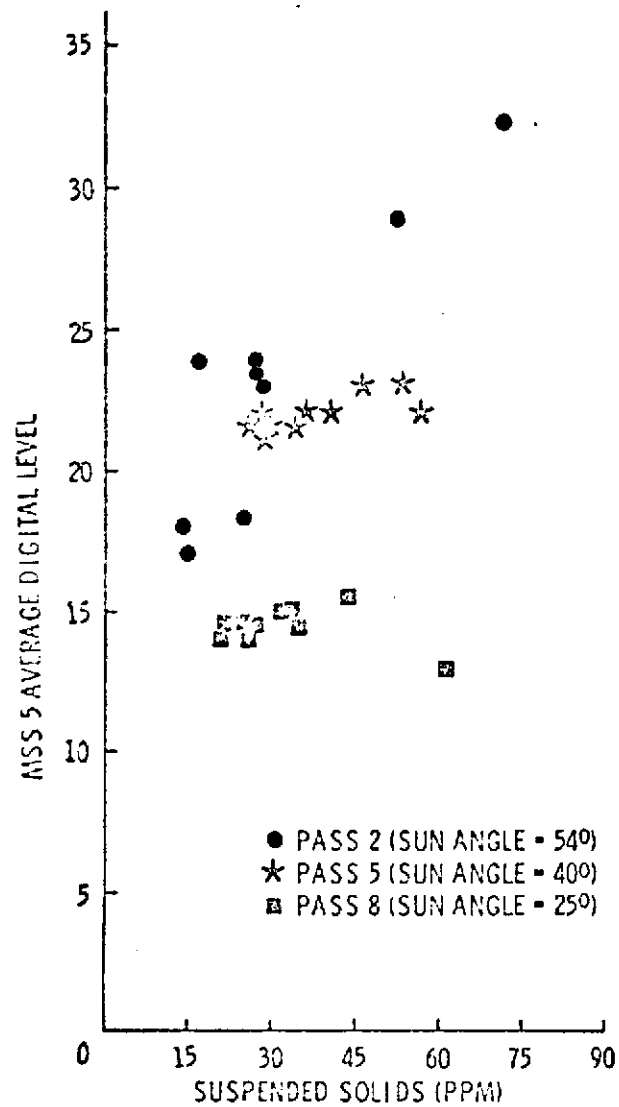


FIGURE 3. MSS5 DIGITAL LEVELS FROM CCT VS. SUSPENDED SOLIDS FOR 28 WATER SAMPLES FROM 3 ERTS-1 PASSES.

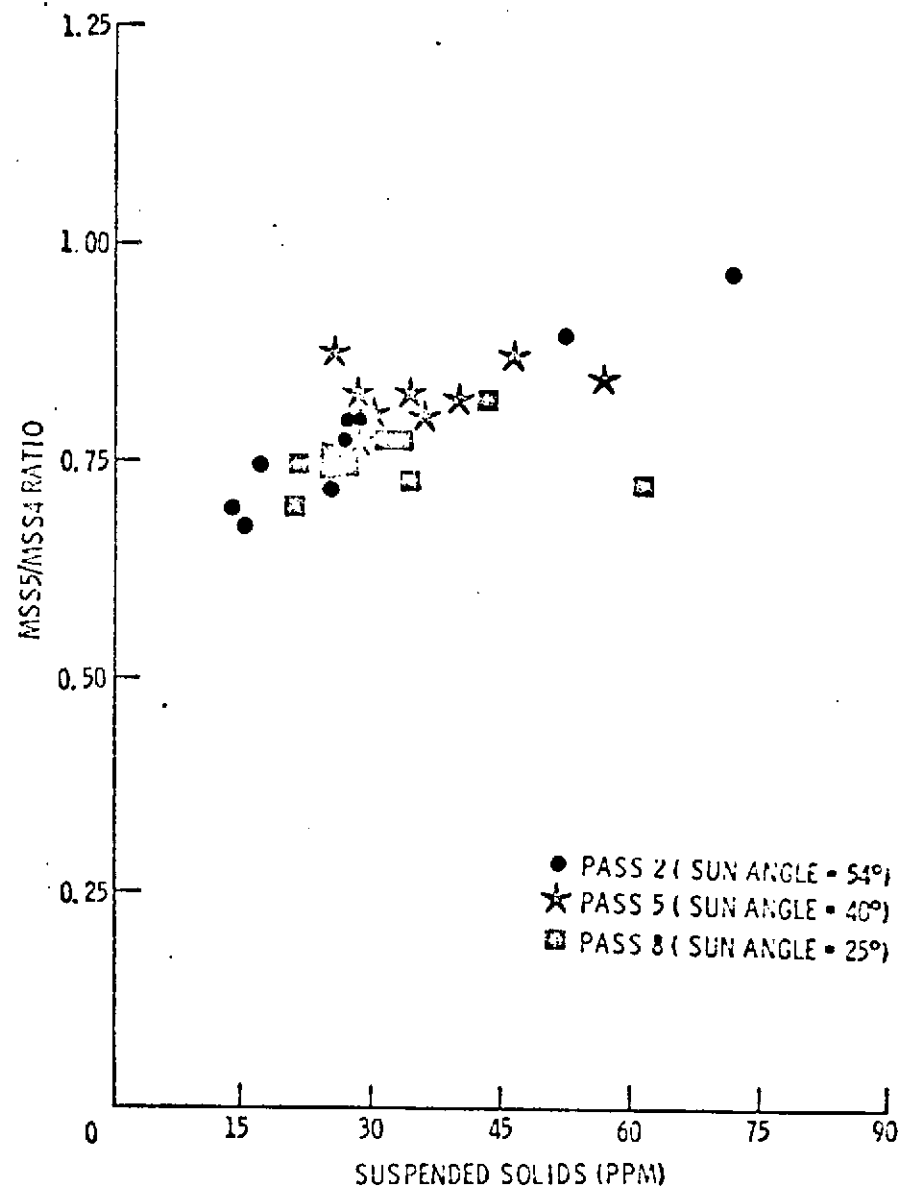


FIGURE 4. MSS5/MSS4 RATIO FROM CCT VS. SUSPENDED SOLIDS FOR 28 WATER SAMPLES FROM 3 ERTS-1 PASSES.

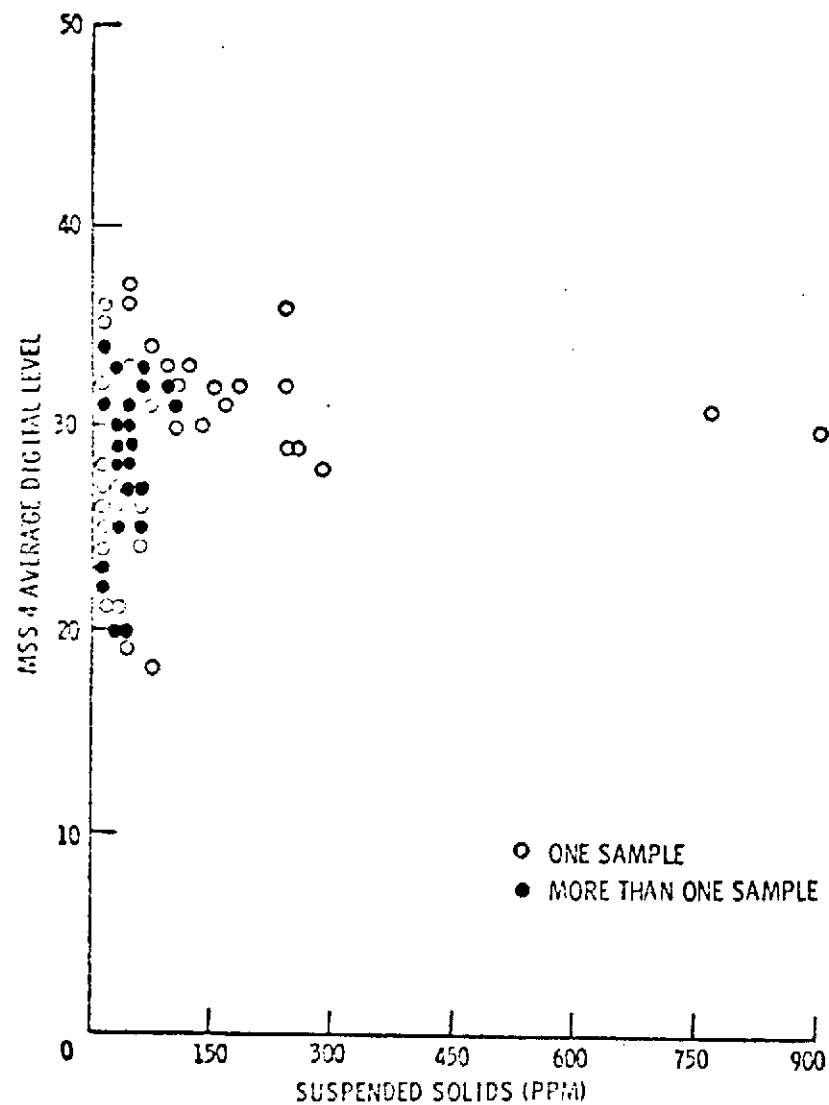


FIGURE 5. MSS 4 DIGITAL LEVEL FROM CCT VS. SUSPENDED SOLIDS FOR 103 WATER SAMPLES FROM 11 ERTS-1 PASSES.

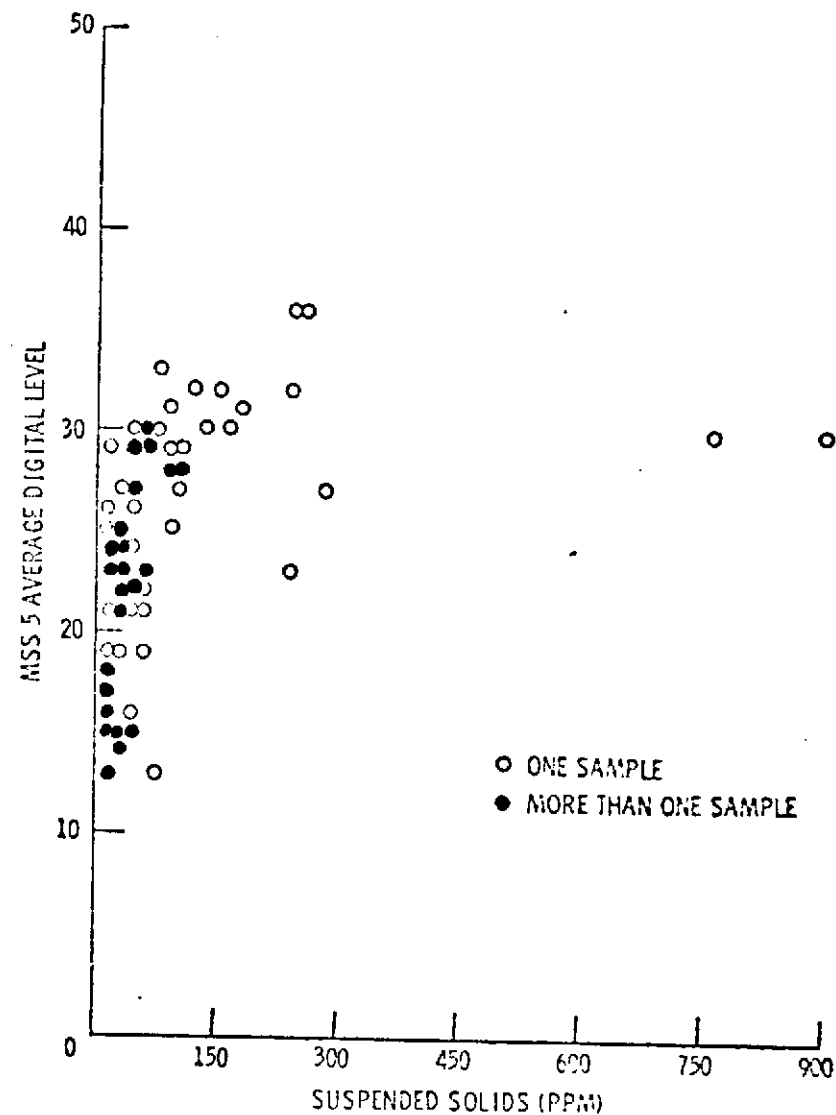


FIGURE 6. MSS 5 DIGITAL LEVEL FROM CCT VS. SUSPENDED SOLIDS FOR 103 WATER SAMPLES FROM 11 ERTS-1 PASSES.

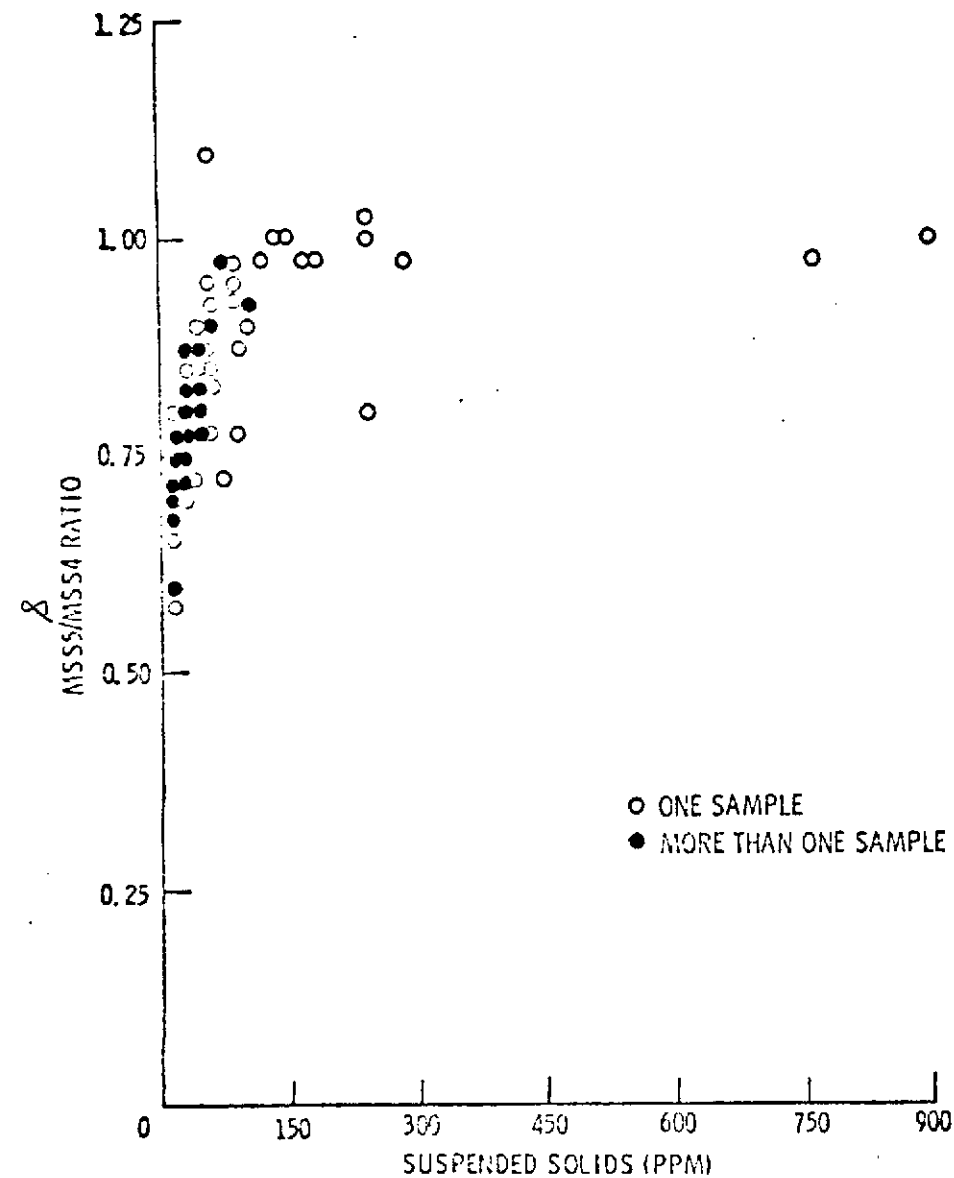


FIGURE 7. MSS5/MSS4 RATIO FROM CCT VS. SUSPENDED SOLIDS FOR 108 WATER SAMPLES FROM 11 ERTS-1 PASSES.

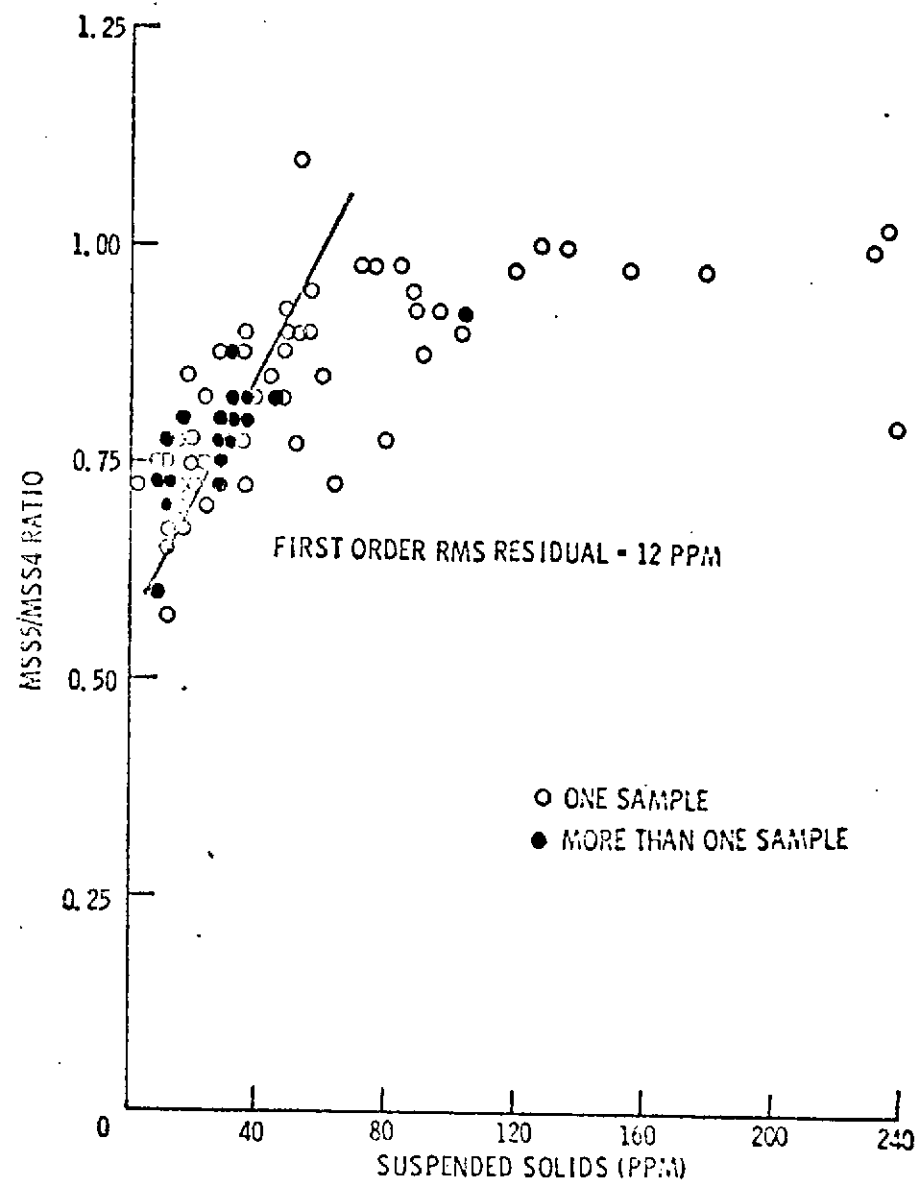


FIGURE 8. MSS5/MSS4 RATIO FROM CCT VS. SUSPENDED SOLIDS FOR 108 WATER SAMPLES FROM 11 ERTS-1 PASSES.

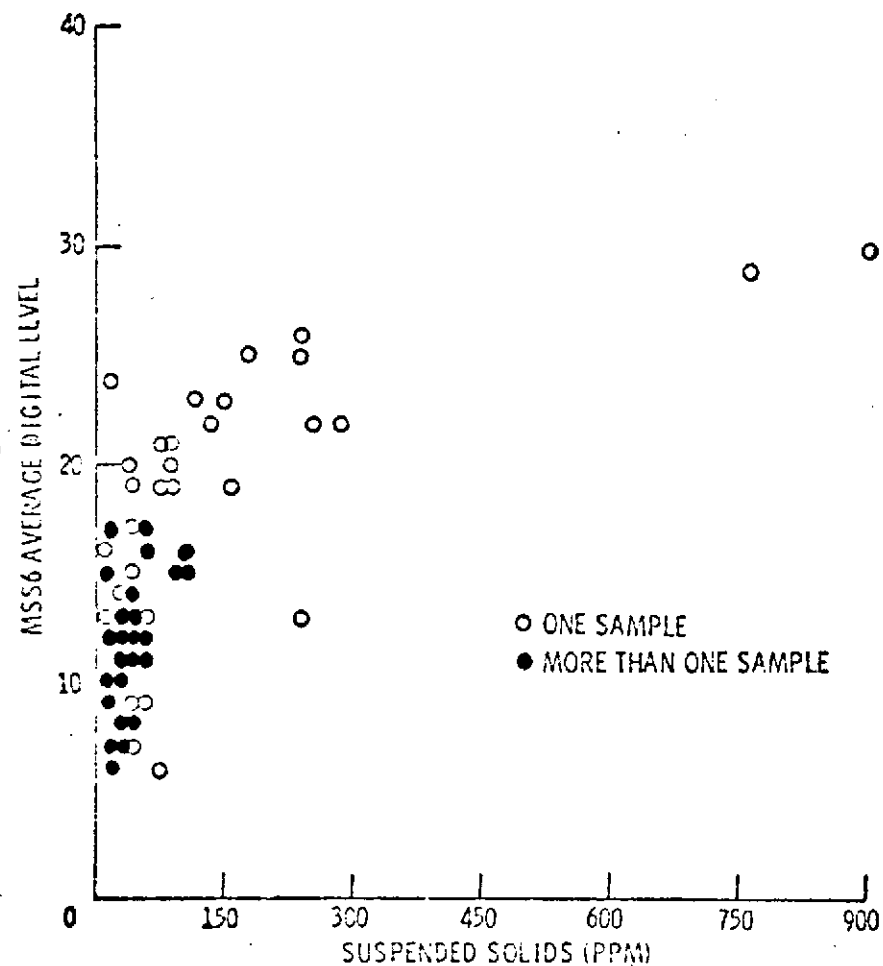


FIGURE 9. MSS6 DIGITAL LEVEL FROM CCT VS. SUSPENDED SOLIDS FOR 108 WATER SAMPLES FROM 11 ERTS-1 PASSES.

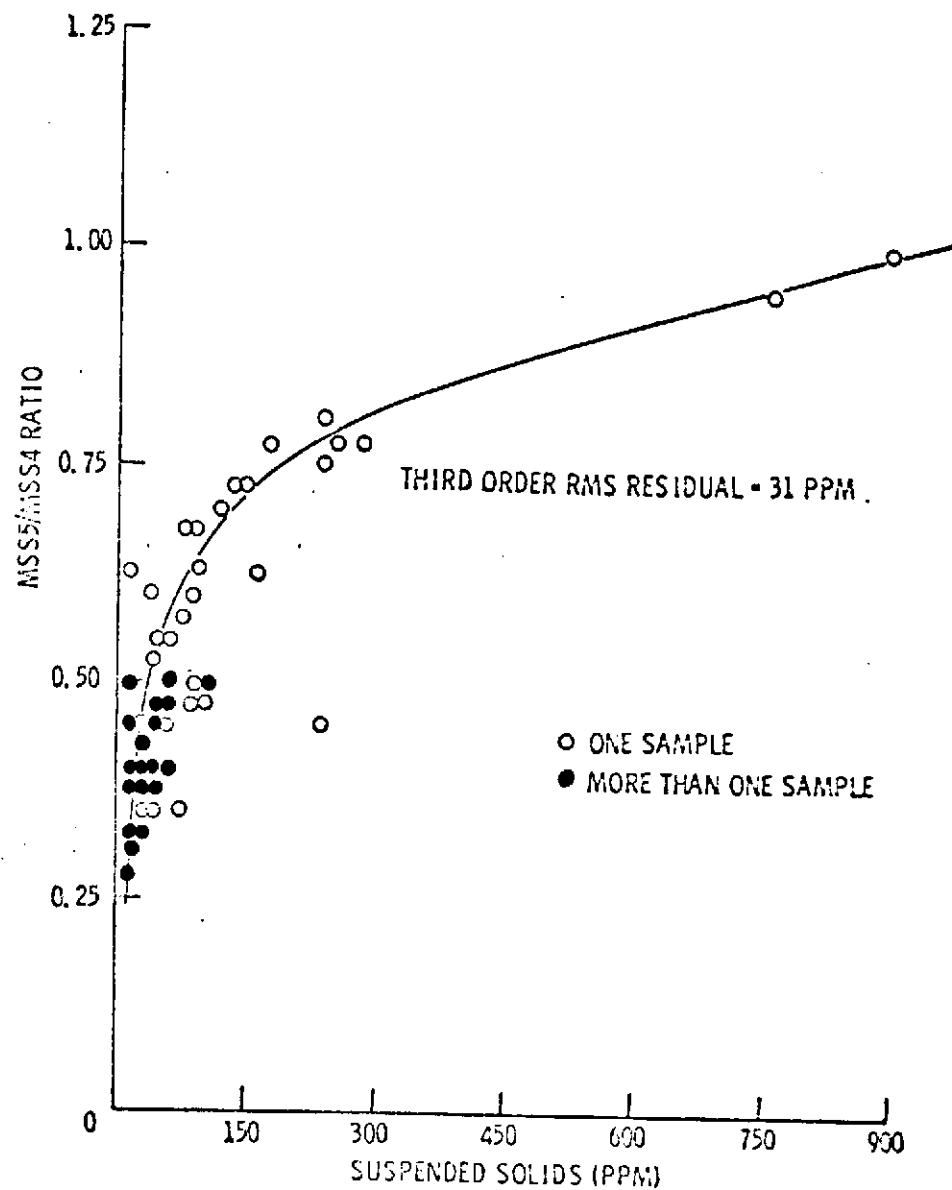


FIGURE 10. MSS6/MSS4 RATIO FROM CCT VS. SUSPENDED SOLIDS FOR 107 WATER SAMPLES FROM 11 ERTS-1 PASSES.

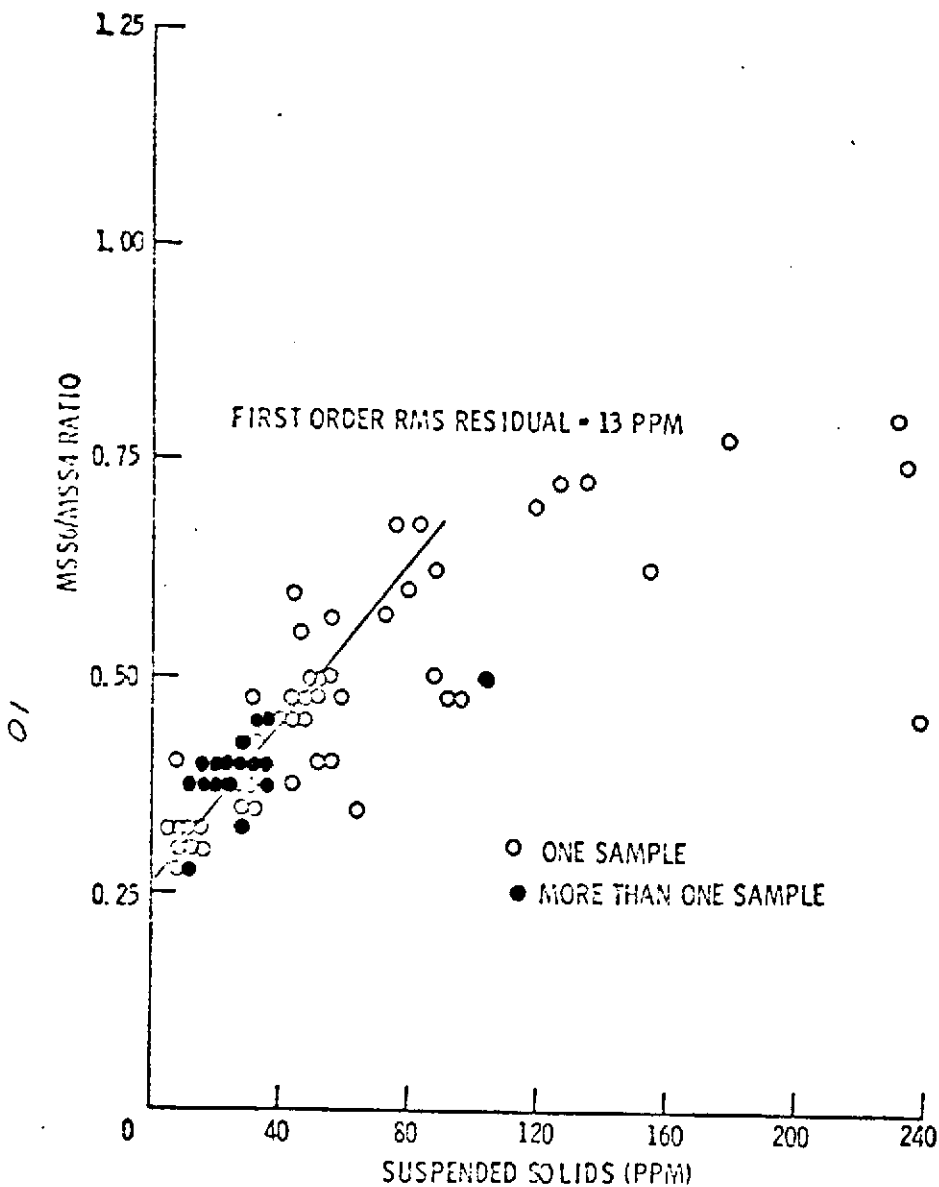


FIGURE 11. MSS6/MSS4 RATIO FROM CCT VS. SUSPENDED SOLIDS FOR 97 WATER SAMPLES FROM 10 ERTS-1 PASSES.

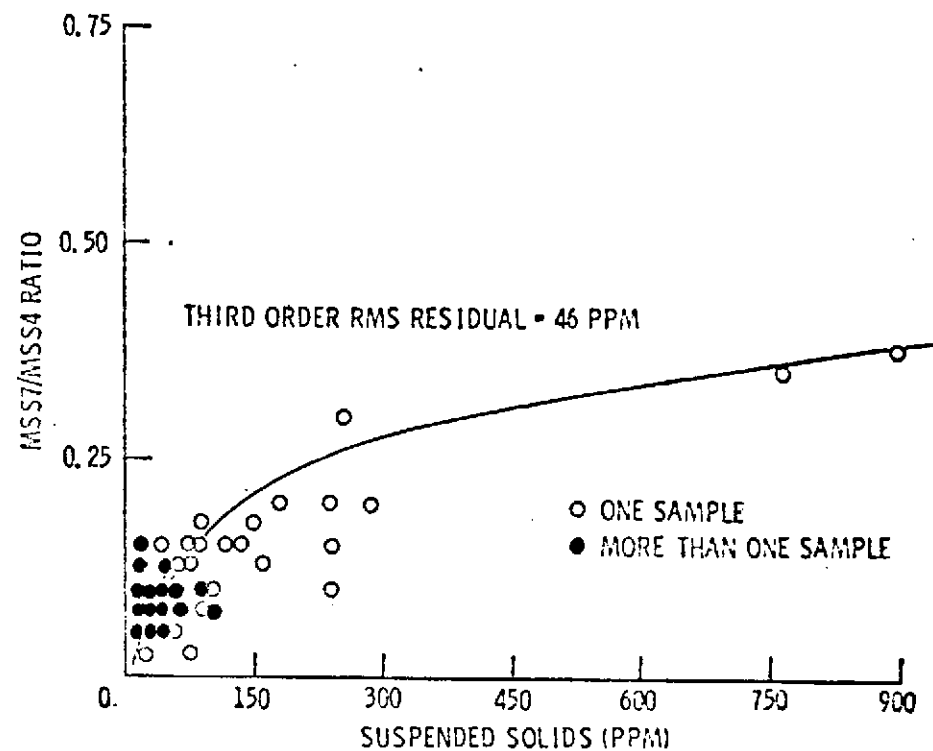


FIGURE 12. MSS7/MSS4 RATIO FROM CCT VS. SUSPENDED SOLIDS FOR 108 WATER SAMPLES FROM 11 ERTS-1 PASSES.

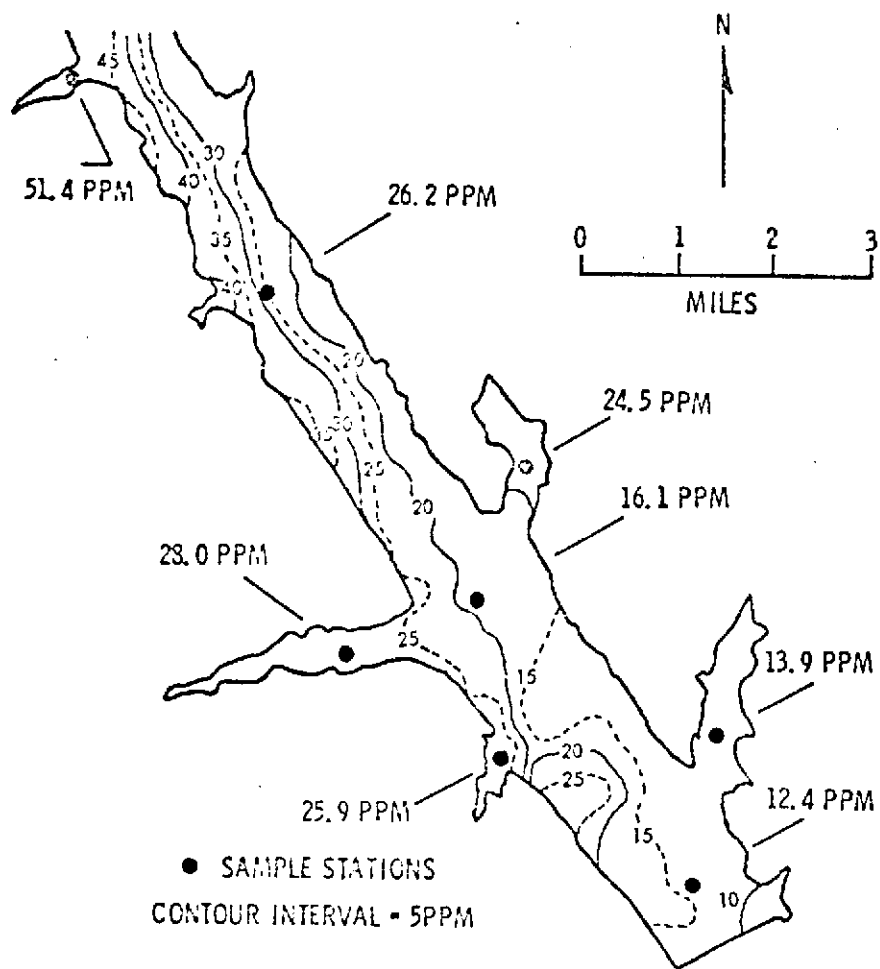


FIGURE 13. SUSPENDED SOLIDS CONTOUR MAP OF TUTTLE CREEK RESERVOIR (AUGUST 14, 1972 ERTS-1 ID NO. 1022-16391-5) DERIVED FROM CCTS (MSS 5) FOR 4 ERTS-1 PASSES.

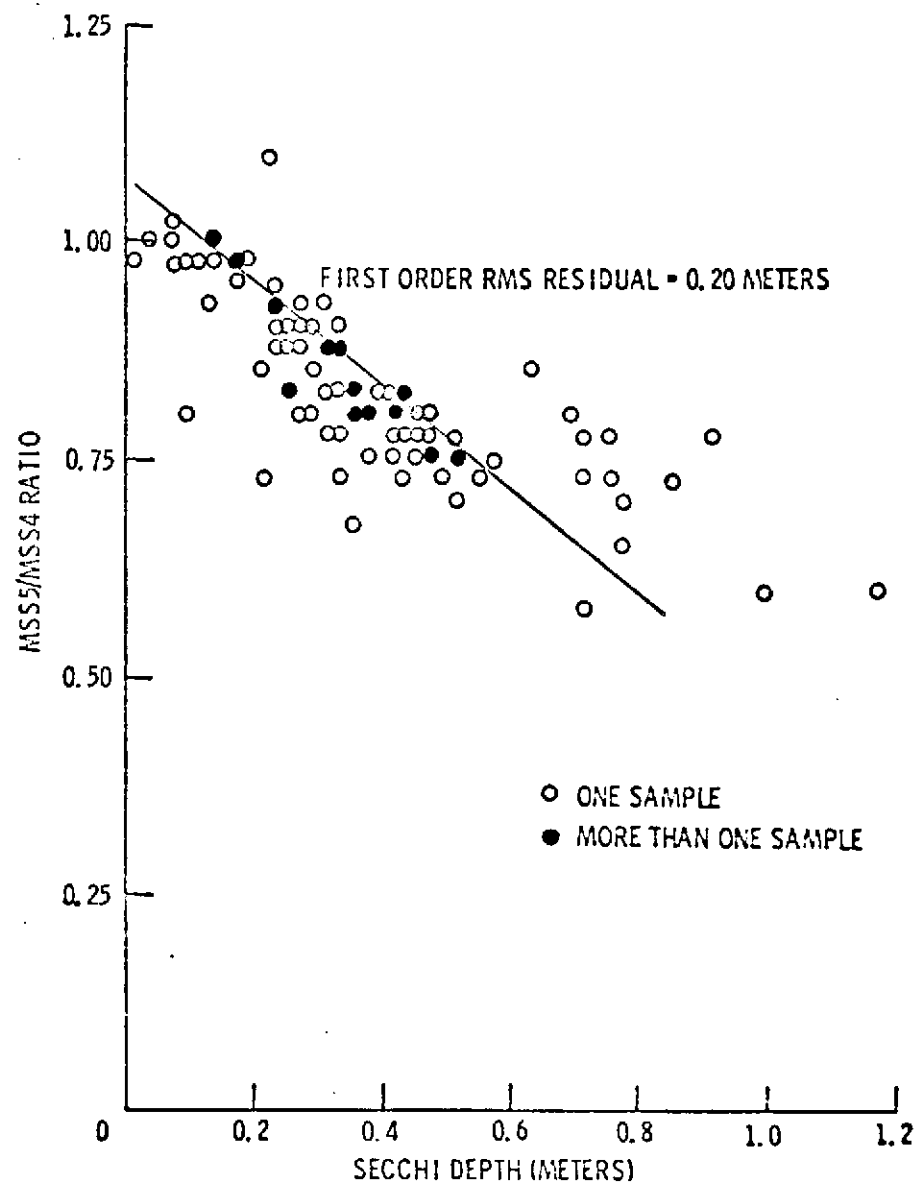


FIGURE 14. MSS5/MSS4 RATIO FROM CCT VS. SECCHI DEPTH FOR 97 SAMPLE STATIONS FROM 10 ERTS-1 PASSES.

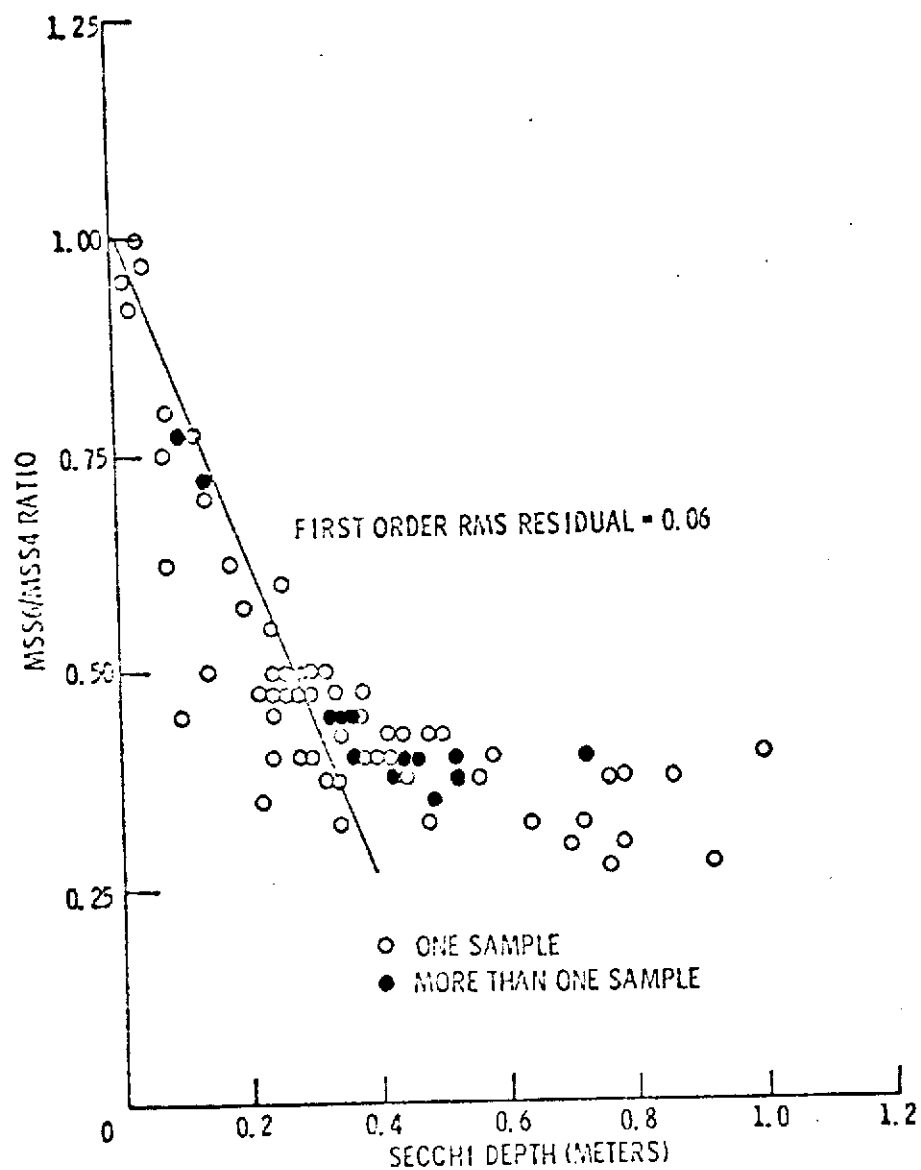


FIGURE 15. MSS6/MSS4 RATIO FROM CCT VS. SECCHI DEPTH FOR 96 SAMPLE STATIONS FROM 10 ERTS-1 PASSES.

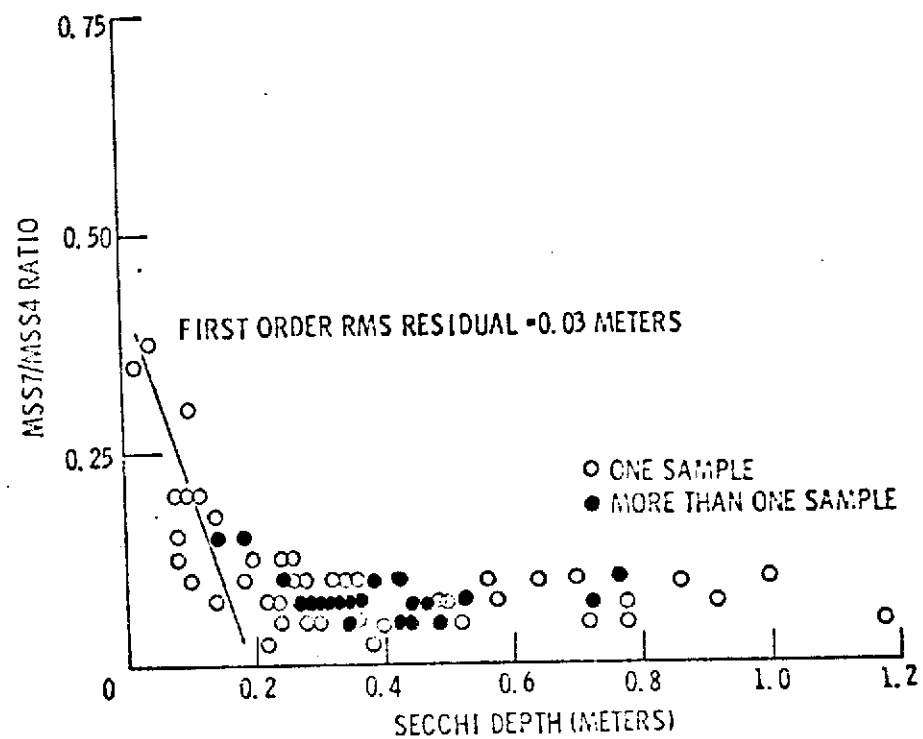


FIGURE 16. MSS7/MSS4 RATIO FROM CCT VS. SECCHI DEPTH FOR 97 SAMPLE STATIONS FROM 10 ERTS-1 PASSES.

CRINC LABORATORIES

Chemical Engineering Low Temperature Laboratory

Remote Sensing Laboratory

Flight Research Laboratory

Chemical Engineering Heat Transfer Laboratory

Nuclear Engineering Laboratory

Environmental Health Engineering Laboratory

Information Processing Laboratory

Water Resources Institute

Technology Transfer Laboratory